



ENHANCING VISUAL INTELLIGENCE USING 3D E-WORKSHEETS WITH THINK PAIR SHARE ON MOLECULAR SHAPES

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ABSTRACT

The understanding of molecular form materials requires a high level of visual spatial skills, but most high school students still show low visual intelligence since the content is abstract and there isn't any interactive digital media. The goal of this project is to enhance students' visual intelligence regarding the submaterial of molecular shapes by creating 3D-assisted e-worksheets that are integrated with the Think Pair Share (TPS) paradigm. The 4D model (define, design, develop) is used in this development research. Involving 35 students in grades XI-3 of SMA Hang Tuah 1 Surabaya and three expert validators. Data was collected through validation sheets, response questionnaires, activity observation sheets, and visual intelligence pretest-posttests including four indicators: imagination, conception, problem solving, and pattern search. The results showed that the e-worksheets were declared valid with all ≥ 4 medians, practical with 96.43% student responses and 99.4% activity implementation, and effective according to the Wilcoxon Signed-Rank test ($Z = -5.165$, $p = 0.000$) with an average increase of 56.90 points and all students experienced an increase in scores. The highest increase occurred in the pattern search indicator (64.24 percentage points). 3D-assisted electronic worksheets integrated with TPS have proven to be effective in bridging abstract molecular representations with students' visual intelligence, so they can be an alternative learning medium for abstract chemistry materials at the high school level.

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1. INTRODUCTION

Education is defined as the process by which individuals carry out in a planned and conscious manner to help each individual actively develop his or her potential, through education it is possible for each individual to be able to play an active role in the community environment (Pratomo et al., 2021). 21st century education is specifically geared towards equipping learners with adaptive skills that are responsive to the increasingly dynamic and complex changing times (Trilling & Fadel, 2010). In this context, science learning at the upper secondary education level requires students to build a deeper understanding, one of which is through chemistry subjects (Rahmawan et al., 2024). In science learning, chemistry has an important role because it bridges

various concepts in science (Muderawan et al., 2019). Chemistry focuses not only on the product of facts and principles, but also on the scientific process that involves scientific thinking skills and attitudes (Zainul, 2021). However, students frequently struggle to grasp abstract chemical properties, particularly due to the challenge of making the connection between symbolic representations and submicroscopic occurrences (Sariati et al., 2020; Zakiyah et al., 2018). The shape of molecules, which necessitates the ability to see the arrangement of atoms and the repulsive force of electron pairs in three dimensions, is one of the most difficult materials (Salim et al., 2022; Awida & Azra, 2024). The findings demonstrated that most students still struggled to comprehend the visual depiction of molecular forms because they were unable to envision submicroscopic objects and did not employ visual-based learning resources (Palma et al., 2021). Hulu & Dwiningsih (2021) found that 67% of students of SMK Negeri 1 Cerme Gresik considered chemistry to be a difficult lesson, especially in molecular form materials. A multi-representation strategy that incorporates the three levels of chemical representation macroscopic, symbolic, and submicroscopic can be used to get around this problem, as formulated by Johnstone (1982) and further developed by Gilbert & Treagust (2009). This approach encourages learners to meaningfully understand chemical phenomena through the connection between symbols, texts, and visual models that complement each other (Ainsworth, 2006; McClary & Talanquer, 2011). Thus, the selection of learning media that is able to present these three levels of representation in an integrated manner is an urgent need in the context of learning molecular forms.

The understanding of molecular shapes is closely related to visual intelligence. Gardner (1983) defines it as the individual's capacity to mentally visualize, describe, and create spatial representations, including imagination, conceptualization, problem-solving, and pattern recognition (Yaumi, 2017). Individuals with high visual intelligence are able to understand visual concepts better, including in chemistry learning that demands an understanding of three-dimensional molecular representations (Ikhsan et al., 2025). Recent research shows that the visual intelligence of high school students is still in the low category due to teacher-centered learning and the lack of interactive digital media (Thayban et al., 2024; Maryam et al., 2025). The findings of pre-research at Hang Tuah 1 Senior High School Surabaya verified this situation. Up to 61.3% of students said that chemistry is a challenging subject to learn, and 74.2% of them reported having particular trouble with the molecular formations sub-material. Further observation shows that most teachers still rely on conventional media in the form of whiteboards and two-dimensional drawings, while the use of digital-based multimedia has not been systematically optimized. This condition indicates the urgency of developing innovative learning media that is able to present three-dimensional representations of molecular shapes to support the development of a more robust conceptual understanding. One potential solution to answer this problem is the advancement of learning through multimedia based on three-dimensional (3D) visualization. According to Ivers & Barron (2010), Multimedia is an integration of text, images, animations, videos, and audio that supports the interactive learning process. Three-dimensional-based media specifically allows students to explore molecular structures in depth and concretely (Nazalin & Muhtadi, 2016; Hoe et al., 2019). In this case, e-worksheets are the right form of implementation because they combine independent learning activities with interactive digital visuals (Ramadhani, 2020). The use of 3D visual elements in e-worksheets can help students understand molecular structures concretely while training students' visual intelligence (Nugroho & Pramono, 2017).

The quality of the learning process is also significantly influenced by learning models in addition to learning media. Students were more engaged and cognitively involved in group discussions than in individual learning, according to observations made during the Introduction to the School Field at SMA Hang Tuah 1 Surabaya. This suggests that the Think Pair Share (TPS) model is applicable. Frank Lyman's model involves three main stages, namely thinking, pairing, and sharing which are in line with the principles of constructivism (Arends, 2012; Trianto, 2017). A number of recent studies have proven that the implementation of the TPS model combined with visual media is able to significantly improve the ability of chemical representation and understanding of abstract concepts in students (Setiani & Hendikawati, 2024; Yunitasari et al., 2025). The research of Safitri & Dwiningsih (2020) proves the efficacy of interactive multimedia based on 3D virtual modeling in improving understanding of the concept of intermolecular forces, but the study has not examined molecular-shaped materials that inherently require higher spatial capabilities. On the other hand, research integrating TPS models with digital media is still limited to the general context and has not measured its impact on visual intelligence in a specific and measurable way. There is a significant research gap in this area: previous studies have mostly focused on passive 3D multimedia, but the integration of Jmol-based interactive molecular visualizations embedded directly in the cooperative syntax of the Think-Pair-Share (TPS) model to measure visual intelligence in a structured manner is still very limited. The uniqueness of this research lies in the simultaneous integration of three elements that have never been done before, namely Jmol-based interactive molecular visualization in a digital electronic worksheet platform, TPS cooperative learning model, and explicit visual intelligence measurement through four measurable indicators on molecular form submatter.

Based on the research gaps that have been identified, this study aims to: (1) develop an electronic worksheet based on three-dimensional interactive molecular visualization that is integrated with the syntax of the Think Pair Share cooperative learning model on molecular form submaterials; (2) assessing the validity of electronic worksheets developed based on the assessment of material experts and media experts; (3) assessing the practicality of electronic worksheets through the response of teachers and students to the ease of use and implementation of TPS syntax in learning; and (4) to measure the effectiveness of electronic worksheets in improving students' visual intelligence through four measurable indicators on the submaterial of molecular form. The integration of 3D visualization in electronic worksheets is expected to present dynamic representations that help students understand molecular structures more concretely, minimize misunderstandings, and strengthen conceptual understanding. The hypothesis proposed is that the use of three-dimensional visualization-based electronic worksheets integrated with the TPS learning model significantly improves students' visual intelligence on the sub-material of molecular forms, so this study is expected to provide practical contributions in the form of digital learning media that are ready to be implemented, as well as theoretical contributions in the form of strengthening the literature on the relationship between visual intelligence, multirepresentation, and outcomes Learning Chemistry in the Era of Digital Education.

2. METHOD

2.1. Design and Research Approach

The define, design, and develop phases of the Thiagarajan 4D model are covered in this research and development (R&D) study (Thiagarajan, S., Semmel, D. S., & Semmel, 1974). The step of dissemination was not completed because the research was limited to limited trials. In order to enhance students' visual intelligence on molecular form submaterials, the Flip Builder platform was used to create three-dimensional (3D) aided e-worksheets that were combined with the Think-Pair-Share (TPS) cooperative learning approach.

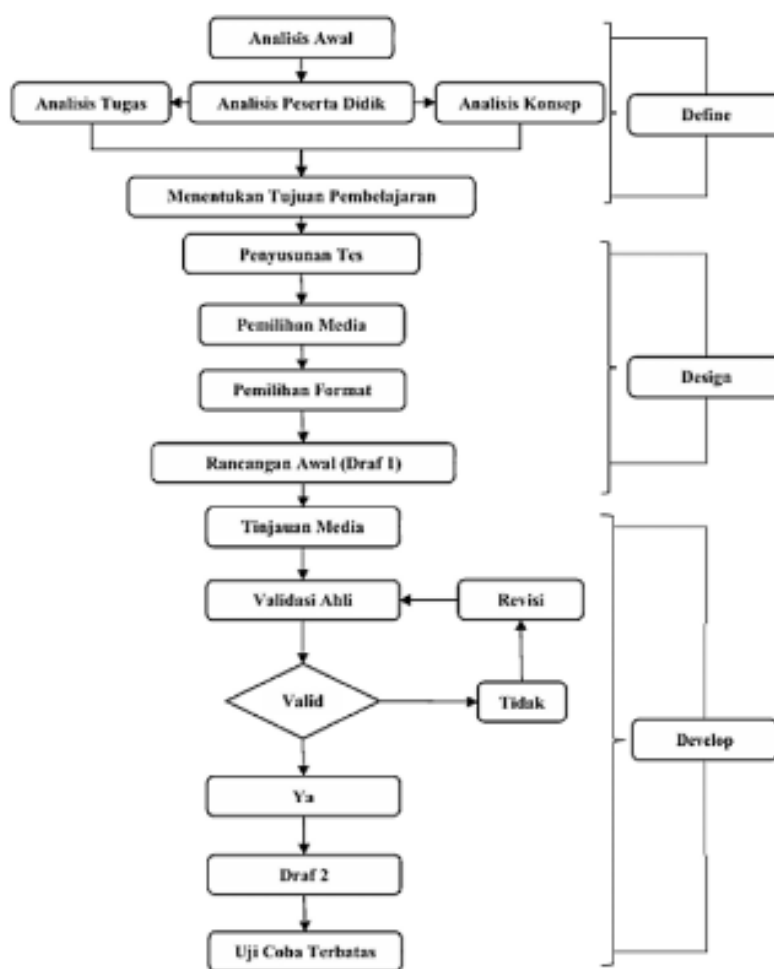


Figure 1. Thiagarajan's 4D research procedure (Yusuf Prasetyo, Ahmad; Grummy Wailandaw, 2023)

2.2. Participants and Subject Picking Techniques

This study involved 35 students from grades XI–3 of Hang Tuah 1 High School Surabaya during the even semester of the 2025–2026 school year served as the study's subjects, selected purposively because of the representativeness of their academic background, who had never used 3D multimedia in chemistry learning, and the full support of the teaching teacher. In addition to

the students, three validators were involved in the product assessment, consisting of two Chemistry Education lecturers at Surabaya State University who were selected for their expertise in chemistry content and learning media development, and one Chemistry teacher at SMA Hang Tuah 1 Surabaya who was selected for their hands-on experience in classroom learning practice, to ensure the accuracy of content, presentation design, and learning implementation.

2.3. Research Location and Time

The study was conducted during the 2025–2026 academic year's even semester. The State University of Surabaya's Chemistry Education Study Program conducted the define and design phases. while the develop stage along with limited trials were carried out at SMA Hang Tuah 1 Surabaya. The role of the researcher includes the design and development of 3D-assisted e-worksheets, the implementation of classroom trials, the administration of all research instruments, and data analysis to assess the validity, practicality, and effectiveness of the media.

2.4. Research Procedure

At SMA Hang Tuah 1 Surabaya, the Define stage was completed by literature review and pre-research, which included initial analysis, student analysis, idea analysis, task analysis, and creation of learning objectives in the ABCD framework. The outcomes of the pre-research showed that 74.2% of students had difficulty understanding the shape of molecules and 58.1% had never drawn them in three dimensions, which confirms the urgency of developing 3D-based media. Preparing research tools (pre- and post-visual intelligence tests based on four indicators: imagination, concept, problem-solving, and pattern finding), validation sheets, Guttman scale response questionnaires, and activity observation sheets. The Flip Builder platform was chosen as the medium for the development of electronic worksheets, with 3D molecular visualizations developed using Jmol through the Sketchfab platform, where the three-dimensional molecular model that has been built on Jmol is uploaded to Sketchfab and further embedded into the Flip Builder using the HTML5 embed method, so that molecular visualizations can be displayed interactively and directly within the pages of the electronic worksheet without the need for a device additional softness. The graphical design of the interface was developed using CorelDraw and Canva. The storyboard is systematically composed including cover components, concept maps, instructions for use, material summaries, 3D animations, TPS syntax-based activities, and evaluations. The Develop phase includes two main activities: (1) expert assessment, where the first draft of the e-worksheets is reviewed by the supervisor and then validated by three validators; and (2) a limited trial for two meetings (4 JP × 45 minutes) face-to-face in class XI-3 of SMA Hang Tuah 1 Surabaya using TPS syntax.

2.5. Methods and Tools for Gathering Data

The validity, usefulness, and efficacy of 3D-assisted e-worksheets were assessed in this study using a number of tools. An overview of the instruments is provided in Table 1.

Table 1. Research Tools and Their Measures

Instruments	Purpose	Indicator	Example Item	Scale
Study Sheet	Initial evaluation of the product by the supervisor	Content, appearance, technical	The material is arranged sequentially and structured	Qualitative (comments & suggestions)
Validation sheet	Measuring the validity of the content and construct of e-worksheets	Suitability of material, visual presentation, language	3D visualization supports the concept of VSEPR	Likert 1–5
Student Response Questionnaire	Measuring the practicality of media	Learning motivation, ease of use, visual clarity	e-worksheets help me visually understand the shape of molecules	Dichotomy (Yes/No)
Activity observation sheet	Evaluate learner engagement	Engagement, participation, interaction with the media	Students simulate the shape of 3D molecules	Percentage of activity frequency
Pretest & Posttest	Measuring students' visual intelligence	Imagination, conception, problem-solving, pattern finding	Determine the 3D shape of the NH ₃ molecule based on the theory of VSEPR	Score 0-100

2.6. Data Analysis Techniques and Conclusion Criteria

Data are analyzed qualitatively and quantitatively through three main approaches.

2.6.1. Validity Analysis

Validation data from the content and construct validity sheets were analyzed using the median per statement item. The use of the median was chosen because the data was ordinal-scale, which only shows the sequence without paying attention to the distances between the categories (Gravetter et al., 2020). The interpretation criteria are presented in Table 2.

Table 2. Likert Scale of Validity (adapted from Riduwan, 2016)

Score	Rating
1	Very Less
2	Not Good
3	Pretty Good
4	Good
5	Excellent

3D-assisted e-worksheets are declared valid if the calculation results show a median of ≥ 4 .

2.6.2. Practicality Analysis

Two sources were used to gather practicality data: student activity observation sheets and student reaction surveys. The following describes the many methods used to analyze the two data sources.

2.6.2.1 Analysis of Questionnaire for Student Response

The Guttman scale was used to examine the student answer questionnaire, as seen in Table 3.

Table 3. Guttman Scale for Response Questionnaire (adapted from Riduwan, 2016)

No	Questions	Criteria	Score
1	Positive	Yes	1
		No	0
2	Negatives	Yes	0
		No	1

The percentage of practicality is calculated by the formula:

$$\text{Practicality} = \frac{\text{Score obtained}}{\text{Maximum score}} \times 100\%$$

2.6.2.2 Analyzing Student Activity Observation Data

The following formula is used to calculate the proportion of frequency of each activity once observers complete the observation data of students' activities during learning:

$$\text{Activity Percentage (\%)} = \frac{\text{Frequency of activity that appears}}{\text{Overall activity}} \times 100\%$$

Following that, the proportion of student response questionnaires and student activity observation sheets are analyzed using the standards outlined in Table 4.

Table 4. Interpretation Criteria for Practicality Scores (adapted from Riduwan, 2016)

No	Criteria	Percentage (%)
1	Excellent	81–100
2	Good	61–80
3	Pretty Good	41–60
4	Not Good	21–40
5	Very Bad	0–20

E-worksheets are declared practical if the percentage of response questionnaire results and activity observation reaches $\geq 61\%$.

2.6.3. Effectiveness Analysis

The Pretest-Posttest Design of One Group ($O_2 - X - O_2$) was used to evaluate the improvement of students' visual intelligence, considering that this study is in the development stage and a limited trial that aims to assess the feasibility and initial effectiveness of the medium before it is implemented more widely. The use of a design without a control group at this stage is in line with the characteristics of research and development, where the main priority is to obtain preliminary evidence that the developed medium is feasible and effective to use, rather than comparing its effects with other conditions. This approach is also supported by the practical limitations of the number of classes available and the need to maintain homogeneous learning conditions during the trial. The statistical method used was adjusted to the data distribution feature of pretest and posttest visual intelligence results.

Prior to the efficacy test, the Shapiro-Wilk test ($n < 50$) was used to determine whether the data were normal using the following criteria:

- a. If the significance value > 0.05 , then the data is normally distributed.
- b. If the significance value < 0.05 , then the data is not normally distributed.

The analysis is followed by a paired sample t-test using the SPSS software to ascertain whether there is a significant difference between the pretest and posttest results in the same group, using the hypothesis:

- a. H_0 : The results of the pretest and posttest following the use of 3D-assisted e-worksheets did not change significantly.
- b. H_1 : Scores on the pretest and posttest differed significantly following the use of 3D-assisted e-worksheets.

Decision-making policy:

- a. If the significance value < 0.05 , then H_0 is rejected and H_1 is accepted.
- b. If the significance value > 0.05 , then H_0 is accepted and H_1 is rejected.

If the data does not meet the assumption of normality, the non-parametric Wilcoxon signed-rank test is used

3. RESULTS AND DISCUSSION

According to the Thiagarajan 4D model, this study is a development research (R&D) that covers the define, design, and develop phases. The disseminate stage was not completed because the research was restricted to a small number of trials. The product produced in the form of 3D-assisted e-worksheets uses the Flip Builder platform which is integrated with the Think-Pair-Share (TPS) cooperative learning approach to enhance students visual comprehension of molecular shape submaterials. The following is described the development process of each stage along with the results obtained.

3.1. Define Stage

Through the five processes of requirements analysis initial analysis, student analysis, idea analysis, task analysis, and learning objective formulation the definition stage seeks to identify learning conditions. The results of the pre-study showed that 74.2% of students had difficulty

understanding the shape of molecules and 58.1% had never drawn them in three dimensions, while teachers still relied on textbooks and verbal explanations with limitations of interactive visual media. The analysis of students reinforced these findings, where students had difficulty imagining molecular geometry from 2D to 3D representation and had low visual intelligence in all four indicators: imagination, conception, problem-solving, and pattern search. Concept analysis identified that the submatter of molecular forms, especially VSEPR theory and hybridization, is the most abstract material that requires the ability to visualize molecular geometry in space, thus becoming the basis for the preparation of 3D animation content in e-worksheets. Task analysis was used to arrange a hierarchical learning activity flow according to the TPS syntax, starting from identifying electron pairs, determining the shape of molecules based on VSEPR, to drawing 3D projections of molecules. The analysis's findings were used to create learning objectives in the ABCD format which include four indicators of visual intelligence: (1) imagining and describing the 3D shape of molecules; (2) conceptualizing the relationship of electron pairs with molecular geometry; (3) solving the problem of determining molecular shapes; and (4) identifying symmetry patterns in various molecular shapes.

3.2. Design Stage

The design stage aims to design a prototype of 3D-assisted e-worksheets before entering the production process. At this stage, research instruments are prepared including visual intelligence pretest and posttest based on four indicators (imagination, conception, problem solving, and pattern search), validation sheets, Guttman scale response questionnaires, and activity observation sheets, all of which have been validated by experts before use. This stage also includes platform selection and storyboard preparation. The Flip Builder platform was chosen because it is able to produce interactive digital books that are flexible to be accessed online and offline, 3D molecular visualizations are developed using Jmol, and interface graphic design is made with CorelDraw and Canva. The storyboard is systematically composed including cover components, concept maps, instructions for use, VSEPR theory and hybridization materials, 3D molecular animation, TPS syntax-based activities, and evaluation, so as to create a learning flow that flows from understanding concepts to strengthening visual intelligence.

3.3. Develop Stage

The stage of develop is the realization stage of the storyboard design into a complete 3D-assisted e-worksheet product using the Flip Builder platform, including two main activities, namely expert assessment and limited trial. The resulting product contains complete components ranging from the cover page, concept map, instructions for use, summary of VSEPR and hybridization materials equipped with animated videos and interactive 3D models of Jmol-based molecules, learning activities based on TPS syntax that contain four visual intelligence indicators, to a bibliography. The first draft was reviewed by the supervisor and revised on the aspects of the difficulty level of the questions, page layout, and contextual explanation of 3D animation, before being validated by three validators (one chemistry instructor at SMA Hang Tuah 1 Surabaya and two chemistry education lecturers at the State University of Surabaya) using a Likert scale of 1–5. The products that have been declared valid are then tested for two meetings (4 JP × 45 minutes) to

35 students in class XI-3, with the flow of pretest implementation, the use of e-worksheets following the TPS syntax, filling out a response questionnaire, and a visual intelligence posttest. The display of the resulting 3D-assisted e-worksheets product is presented in the following image.

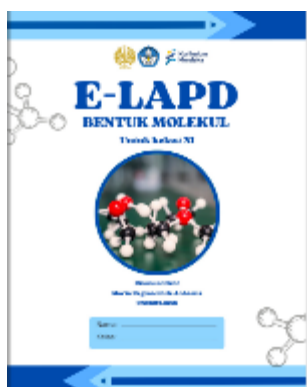


Figure 2. Cover e-worksheets



Figure 3. Developer Profile and Table of Contents



Figure 4. List of Pictures and Preface

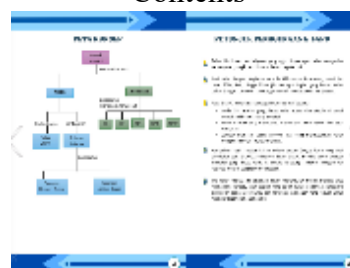


Figure 5. Concept Map and Instructions for Use



Figure 6. Learning Outcomes and Material Summary

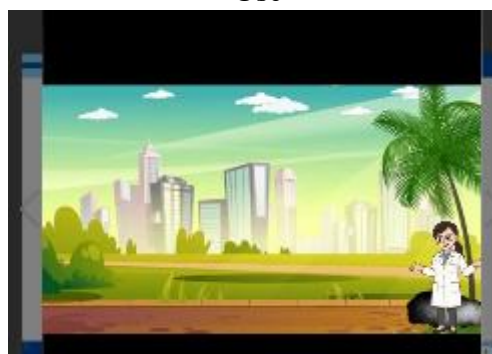


Figure 7. Animated Videos



Figure 8. 3D Molecular Shapes



Figure 9. Learning Activities VSEPR (Imagination)

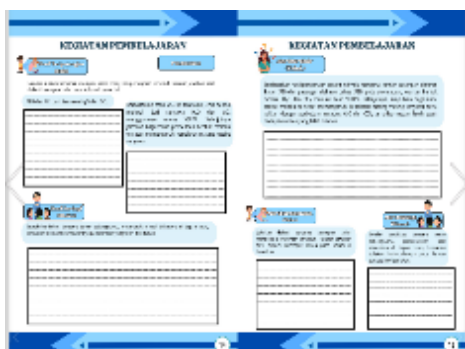


Figure 10. Learning Activities VSEPR (Conception)

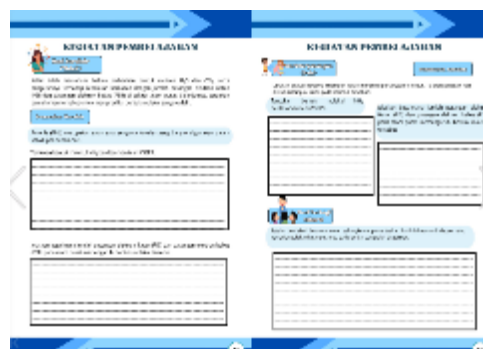


Figure 11. Learning Activities VSEPR (Troubleshooting)

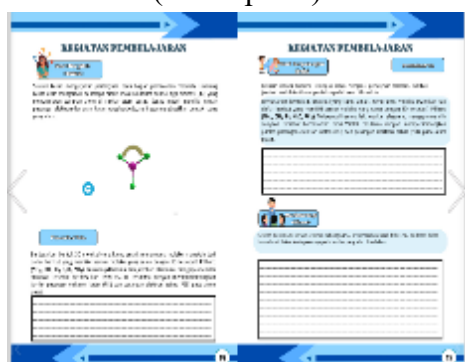


Figure 12. Learning Activities VSEPR (Pattern Search)

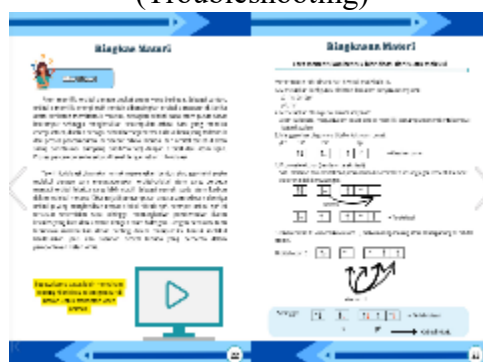


Figure 13. Summary of Hybridization Materials

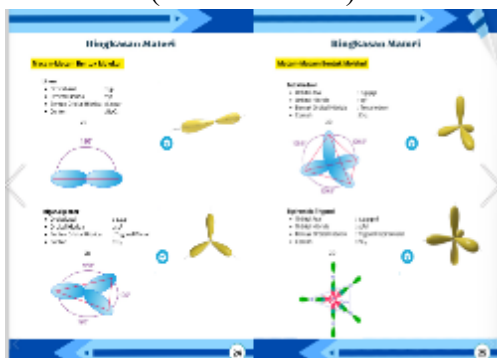


Figure 14. 3D Hybridization

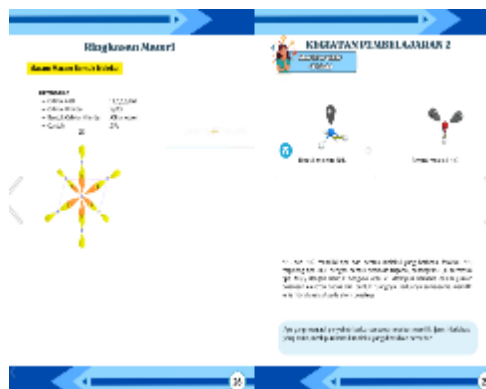


Figure 15. Hybridization Learning Activities

The results of all stages of development are then analyzed and reported in three primary elements, namely the validity, practicality, and effectiveness of 3D-assisted e-worksheets, as explained in the section that follows.

3.4. Validity of 3D Assisted e-worksheets

The validity of 3D-assisted e-worksheets was assessed from two aspects, namely both the construct's and the content's validity. The evaluation was carried out by three validators using a Likert scale of 1–5, and was declared valid if the median value of each aspect was ≥ 4 . The complete validation results are presented in the following Figure.

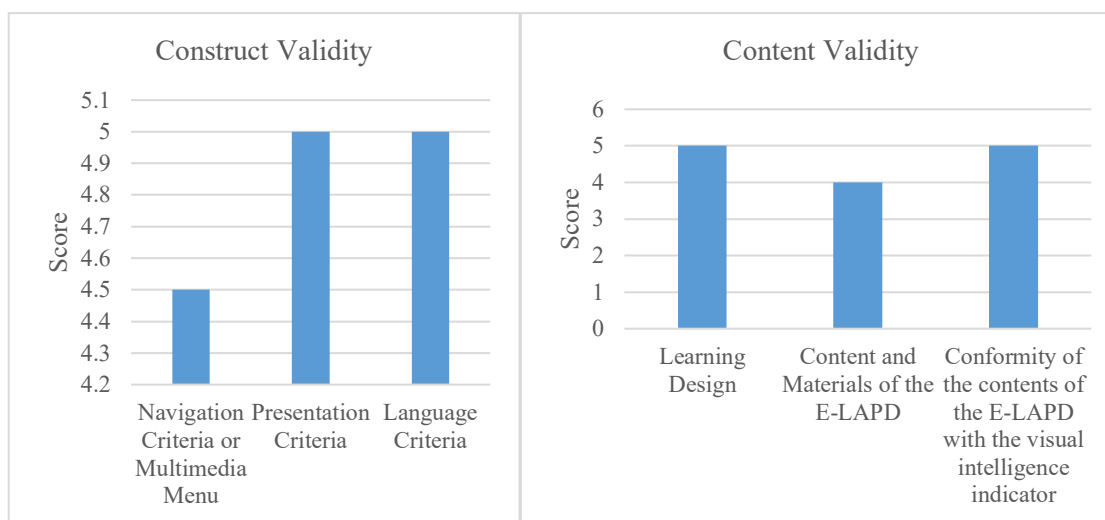


Figure 16. Results of Content Validation and Construct of 3D Assisted e-worksheets

According to the validation results, every component of the 3D-assisted e-worksheets' content and constructs received a median score of at least 4, with aspects of learning design, the suitability of visual intelligence indicators, presentation criteria, and language each obtaining a median of 5 (Excellent), and the multimedia navigation aspect obtained a median of 4.5 (Excellent). Thus, the e-worksheets were declared valid by the three validators because they met the content validity and construct validity criteria as stated Nieveen (1999), That is, The content is created using the latest knowledge and all components are consistent with each other. The high validity of the construct in the aspects of presentation and language also indicates that the e-worksheets have paid attention to the rules of effective visual communication according to the cognitive theory of multimedia learning (Mayer, 2022;Noetel et al., 2022), in line with Sari et al. (2022) and Zakiyah & Dwiningsih (2022) which emphasizes that meeting the standards of content and construct validity is the main requirement for the feasibility of interactive learning media before it is implemented in the classroom.

3.4. Practicality of 3D Assisted e-worksheets

The practicality of 3D-assisted e-worksheets was analyzed based on two data sources, namely the outcomes of student activity observation sheets and surveys. The media is declared practical if the percentage of results of both reaches $\geq 61\%$.

3.4.1 Student Response Questionnaire

The Guttman scale (Yes/No) and five practicality indicators are used in the student response questionnaire. The findings of the summary of the proportion of student answers are displayed in figure 17.

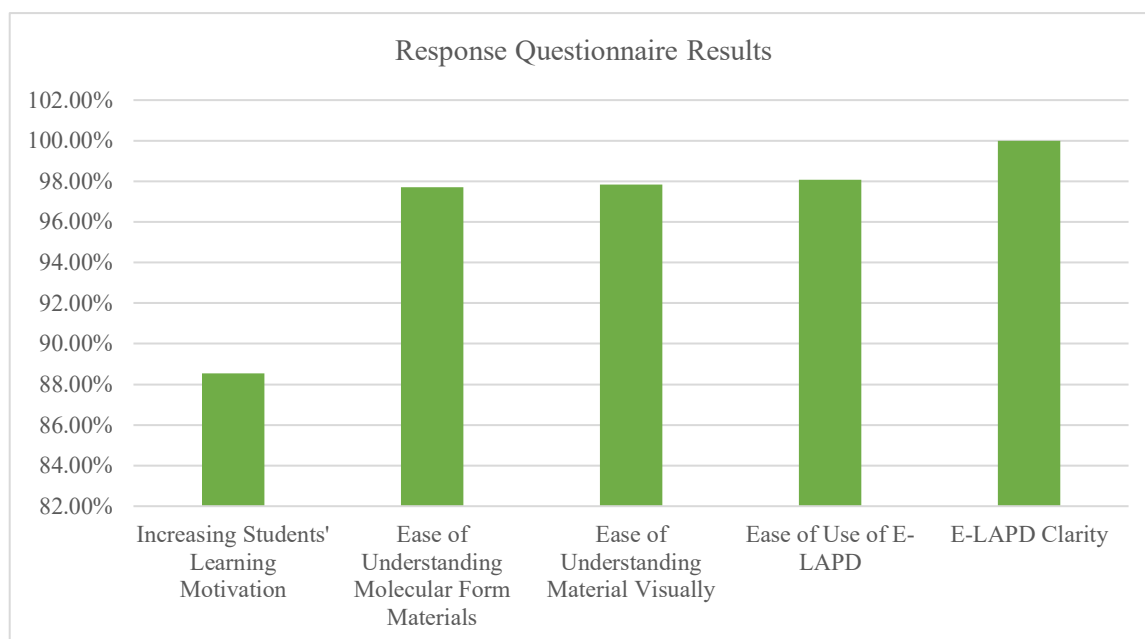


Figure 17. Results of Student Response Questionnaire

Based on Figure 17, the average overall student response reached 96.43% (superior category), but a more meaningful understanding was obtained not from the average number, but from the pattern of differences between indicators. The high indicators of e-worksheet clarity (100%) and visual comprehension (97.83%) simultaneously indicate that the Flip Builder-based interface design combined with Jmol visualization successfully lowers students' extrinsic cognitive load, so that students' cognitive capacity can be fully diverted to meaningfully process 3D molecular representations, in accordance with Cognitive Load Theory (Sweller, 1988). This is an important finding because in the context of the inherently abstract molecular form submatter, media clarity is not just a user's convenience but a major prerequisite for 3D visualization to function as a thinking tool, not just a digital decoration. On the other hand, the relatively lower indicator of learning motivation (88.53%) needs to be interpreted critically, not as a failure of the media, but as an indication that students' intrinsic motivation towards chemistry requires stimulation that requires more than just attractive visual displays, but rather a tiered cognitive challenge and adaptive feedback, as evidenced by Zeng et al. (2024) and Dewitasari & Rusmini (2023) that gamification elements in digital media are proven significantly increase students' intrinsic motivation in science learning, so the future development of e-worksheets needs to consider the integration of these mechanisms, in line with Yamtinah et al. (2023) and Riduwan (2016).

3.4.2 Observation of Student Activities

Practicality was evaluated through observation of students' activities during the learning process in addition to the response questionnaire. The percentage results of each activity are presented in Figure 18.

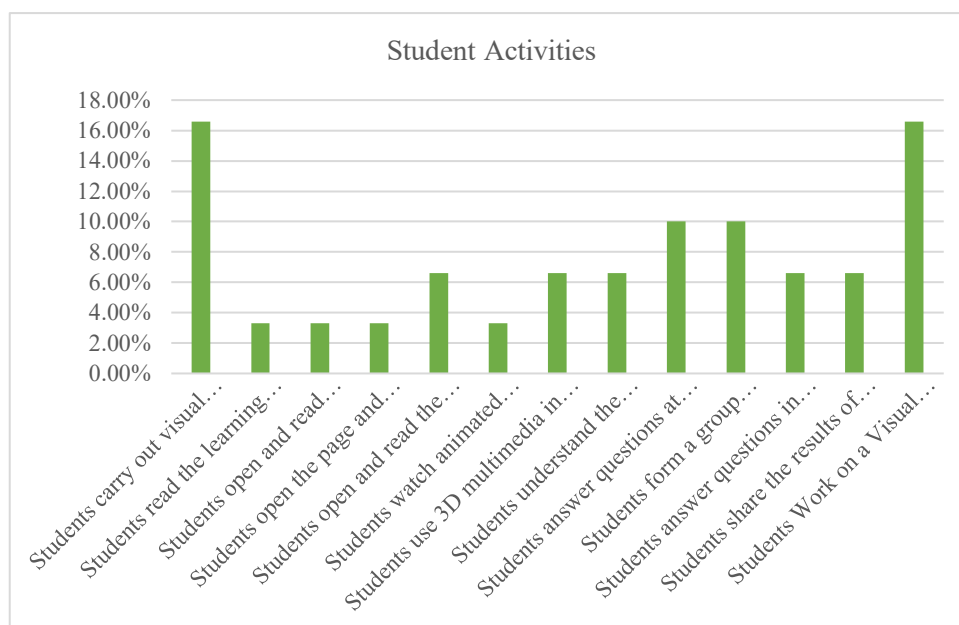


Figure 18. Results of Observation of Student Activities

Based on Figure 18, the implementation of all 13 learning activities reached 99.4%, exceeding the minimum practicality criterion of 61%. However, what is more pedagogically meaningful is not the number of implementation, but what the number reveals about the effectiveness of the instructional design of the e-worksheet. The high implementation at the Think stage (6.6%–10.0%) indicates that the Jmol visualization-based questions in the e-worksheet are successful in provoking students' independent thinking processes, an achievement that is not easy to achieve in conventional chemistry learning where students tend to rely directly on the teacher's explanations when faced with abstract concepts such as molecular geometry. Similarly, the consistent implementation of the Pair and Share stages shows that the syntax structure of the TPS embedded in the e-worksheet serves as a cognitive scaffolding that systematically pushes students from individual thinking towards the construction of shared knowledge, in line with Vygotsky (1978) Zone of Proximal Development principle that social interaction accelerates the internalization of difficult concepts. Thus, the implementation of 99.4% is not just an indicator of procedural compliance, but evidence that the design of the e-worksheet is able to shift the role of the teacher from the conveyor of information to the facilitator, so that students become active agents in building their own visual intelligence of the shape of molecules, in line with Dwiningsih et al. (2022) who prove that 3D molecular interactive multimedia is effective in improving students' spatial abilities in the high-effects category.

3.5. The effectiveness of 3D Assisted e-worksheets

Three stages of analysis descriptive statistics, the Shapiro-Wilk normality test, and the Wilcoxon Signed-Rank Test effectiveness were used to gauge how well 3D-assisted e-worksheets improved students' visual intelligence scores using the One-Group Pretest-Posttest design. The findings of the descriptive analysis are shown in Table 5.

Table 5. Descriptive Statistics of Pretest and Posttest Scores of Visual Intelligence

Statistics	Pretest	Posttest
Mean	32,86	89,76
Std. Deviation	18,73	4,56
Minimum	00,00	83,00
Maximum	75,00	100,00

Based on Table 5, the average visual intelligence pretest score of students was 32.86 (SD = 18.74, min = 0.00, max = 75.00), a substantial increase in the posttest to 89.76 (SD = 4.56, min = 83.33, max = 100.00), with an average increase of 56.90 points. The decrease in standard deviation from 18.74 to 4.56 indicates that learners' scores have become more uniform after learning, indicating that 3D-assisted e-worksheets are able to provide an even learning experience for all learners regardless of their initial ability, in line with Dwiningsih et al. (2022). Next, the data were tested for normality using the Shapiro-Wilk test (n = 35) to determine the exact type of statistical test, with the results presented in Table 6.

Table 6. Shapiro-Wilk Normality Test Results

	Test of Normality					
	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest	,148	35	,050	,960	35	,227
Posttest	,376	35	,000	,716	35	,000

a. Lilliefors Significance Correction

The effectiveness analysis was carried out using the non-parametric Wilcoxon Signed-Rank Test in place of the Paired Sample t-test because Table 6's Shapiro-Wilk test results indicated that the pretest data was normally distributed ($p = 0.227 > 0.05$) while the posttest data was not normally distributed ($p = 0.000 < 0.05$). The pretest and posttest results of the same group were compared using this test, with the hypothesis

H₀: The results of the pretest and posttest do not significantly differ from one another

H₁: The results of the pretest and posttest differ significantly

The rationale for making decisions is that H₀ is rejected and H₁ is accepted if the significant value of $p < 0.05$. The Wilcoxon test results are displayed in Table 7.

Table 7. Wilcoxon Signed-Rank Test Results

Tes Statistics ^a	
	Posttest – Pretest
Z	-5,165 ^b
Asymp. Sig. (2-tailed)	,000

b. Wilcoxon Signed Ranks Test

According to Table 7, the Wilcoxon Signed-Rank Test results revealed a value of $Z = -5.165$ with Asymp significance. Sig. (2-tailed) = 0.000 ($p < 0.05$). As a result, H_0 was rejected and H_1 was accepted, demonstrating the effectiveness of 3D-assisted e-worksheets in raising students' visual intelligence on submaterial in molecular forms. Ranks analysis was performed to ascertain the direction and consistency of the change in all students' scores in order to support these findings; the results are shown in Table 8.

Table 8. Results of Ranks Analysis of the Wilcoxon Signed-Rank Test

		Wilcoxon Signed Ranks Test		
		Ranks		Sum of
		N	Mean Rank	Ranks
Posttest - Pretest	Negative Ranks	0 ^a	,00	,00
	Positive Ranks	35 ^b	18,00	630,00
	Ties	0		
	Total	35		

- a. Posttest < Pretest
- b. Posttest > Pretest
- c. Posttest = Pretest

Based on Table 8, the results of the Ranks analysis showed that all 35 students (100%) obtained posttest scores higher than the pretest (Positive Ranks = 35, Mean Rank = 18.00, Sum of Ranks = 630.00), with Negative Ranks = 0 and Ties = 0, confirming that 3D-assisted e-worksheets had an equal positive impact on all students without exception. In addition, the improvement of visual intelligence was also analyzed per indicator to find out the aspects that experienced the most significant improvement, with the results presented in Table 9.

Table 9. Comparison of Visual Intelligence Score Percentage Per Indicator

Visual Intelligence Indicators	Pretest (%)	Posttest (%)	Improvement (%)
Imagination	46,90	71,40	24,50
Conception	41,67	84,80	43,13
Troubleshooting	35,43	89,53	54,10
Pattern Search	28,13	92,37	64,24

Based on Table 9, the pattern of improvement of the four indicators of visual intelligence holds a deeper meaning than just a sequence of numbers. The highest increases in pattern finding indicators (28.13% → 92.37%, +64.24 points) and problem-solving (35.43% → 89.53%, +54.10 points) are not accidental, but rather a direct consequence of Jmol-based activity design that allows students to rotate, manipulate, and compare molecular models interactively. Direct interaction with the 3D model repeatedly encourages students to actively search for the regularity of geometry between molecules, a cognitive process that specifically trains pattern-finding and spatial problem-solving abilities that cannot be stimulated by static 2D representations. A significant increase in

conception indicators (41.67% → 84.80%, +43.13 points) also indicates that the integration of TPS syntax in the e-worksheet is important, as the Pair and Share stages encourage students to externalize and restructure their conceptual understanding through discussion, thus strengthening the connection between the molecular visual representation and the underlying VSEPR concept. On the contrary, the relatively lower increase in the imagination indicator (46.90% → 71.40%, +24.50 points) needs to be interpreted critically as a finding that actually opens the agenda for further research, since imagination as an internal cognitive process requires a deeper and continuous internalization that cannot be achieved in just two learning meetings, as affirmed by Abdo et al. (2024) that the development of imaginative-spatial capacity requires exposure to stimulus Scheduled and tiered visuals in the long run.

Significant improvements in all indicators confirm that 3D-assisted e-worksheets are able to be a cognitive bridge between abstract representations of molecules and learners' visual intelligence, consistent with the dual coding principle which states that simultaneous processing of information through verbal and visual channels improves learning (Wooten & Cuevas, 2024;Kiernan et al., 2024). The high improvement in pattern finding and problem-solving indicators shows that direct interaction with Jmol-based 3D molecular models is effective in developing learners' high-level thinking skills, in line with Hoai et al. (2023) which proves that 3D simulation is superior to two-dimensional media in driving the transfer and application of spatial chemical content. The results of the Wilcoxon test with $p = 0.000$ and Positive Ranks = 35 (100%) indicate that the positive effect of 3D assisted e-worksheets is universal and equitable across all learners regardless of their initial ability, in keeping with the idea of Universal Design for Learning (Ismailov & Chiu, 2022;King-Sears et al., 2023) which emphasizes the importance of designing media that accommodates a diversity of learning styles. Thus, 3D-assisted e-worksheets have proven to be not only statistically effective, but also inclusive in providing a meaningful learning experience for all students.

4. CONCLUSION

This study succeeded in developing 3D-assisted e-worksheets that were integrated using the Think Pair Share method of instruction and proved to be valid, practical, and effective in improving the visual intelligence of grade XI students on the submaterial of molecular forms. The e-worksheets achieved full validity with all aspects of content and constructs obtaining a median score of ≥ 4 , which confirmed their feasibility to be implemented in the classroom. Practicality was determined through a percentage of student response of 96.43% and the implementation of learning activities of 99.4%, both in the very good category. Effectiveness was proven through a significant increase in visual intelligence scores in all four indicators, namely imagination, conception, problem-solving, and pattern search. The pattern search indicator recorded the highest increase of 64.24 percentage points, and all 35 students showed an increase in scores after using the media. These results confirm that the integration of interactive 3D visualization with TPS cooperative learning effectively bridges the cognitive gap between abstract molecular representations and students' spatial understanding. For further research, it is recommended that the research be expanded to a broader dissemination stage, integrating gamification elements to further encourage learners' intrinsic motivation, as well as exploring the application of similar 3D-assisted media to other abstract chemistry topics such as atomic orbitals and intermolecular forces.

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